

Suprasternal cross-sectional echocardiography in assessment of patent ductus arteriosus

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SUMMARY Ninety-four patients with patent ductus arteriosus, whose ages ranged from 28 weeks gestation to 8 years, were assessed by suprasternal cross-sectional echocardiography. A further group of 37 cases without a patent ductus arteriosus were assessed by the same technique.

The appearances of the ductus via this approach varied according to the ventriculoarterial connections. Reliable assessment of patency was possible in 87 cases. In seven cases where the ductal lumen was less than 2 mm in size, a false negative diagnosis was made. In the 37 patients without a patent ductus arteriosus, no false positive diagnoses were made. Suprasternal cross-sectional echocardiography enables a reliable assessment of ductal patency, provided the lumen falls within the range of lateral resolution of the equipment being used.

Patent ductus arteriosus is one of the commonest congenital cardiovascular abnormalities. It may occur in isolation, or more frequently in association with other intra- or extracardiac malformations. The characteristic signs are often absent in the neonate, because of the normal increase in pulmonary artery pressure seen in this age group. Similarly when a major cardiac malformation is present, the signs of the primary defect often mask those of a patent ductus arteriosus, even though it may be playing a significant haemodynamic role. For all these reasons, a reliable non-invasive method of assessing patency of the ductus at a single point in time would be advantageous. Such a technique would be even more valuable if it enabled the monitoring of changes in the ductus with time, whether these were spontaneous or induced by pharmacological manipulation.

The precordial echocardiographic approach has been tried,¹ but this view foreshortens the ductus, thereby making interpretation difficult. Not infrequently, particularly in the sick neonate, it is difficult to obtain a reliable window. The suprasternal approach seemed appropriate for the assessment of the ductus. The aims of the study were to test the hypothesis and assess the validity and reliability of this approach.

Subjects and methods

All the patients were drawn from the routine work at The Hospital for Sick Children, Great Ormond Street. The cases were studied with an Advanced Technology Laboratory Mechanical Sector Scanner, using a 3.0 or 5.0 MHz transducer. In all patients either angiocardio-graphic, surgical, or necropsy confirmation of the diagnosis was available. The children were studied prospectively, the results obtained then being compared with those from invasive techniques. Their ages ranged from 28 weeks gestation to 8 years.

The transducer was initially placed in the suprasternal notch, such that the beam was parallel to the frontal plane of the body. In this cut, firstly the adequacy of the suprasternal window could be judged and secondly the relation of the aorta and right pulmonary artery could be determined.

It must be stressed that in some patients the best window was obtained with the transducer slightly to the right of the suprasternal notch, while in others the best position of the scan head was just below the left clavicle.

Next the transducer was rotated anticlockwise in the presence of a left sided arch to visualise the aorta in its long axis (clockwise with a right arch). In this cut the brachiocephalic vessels could be assessed and the lumen of the aorta visualised. The main pulmonary artery could be seen in the crook of the aortic arch. The scan head was then angled towards the patient's left side to visualise the left pulmonary artery and its relation to the descending aorta.

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Next, with further anterosuperior angulation, the main and left pulmonary arteries could be seen including the pulmonary valve. The presence or absence of a patent ductus arteriosus was assessed from the region immediately above the left pulmonary artery. Great care was taken to visualise both the aortic and pulmonary ends if a ductus was present.

Results

In five cases it was not possible to obtain an adequate suprasternal window, because of associated respiratory problems and secondary hyperinflation of the chest. These cases were excluded. The remaining group consisted of 131 cases: 83 cases were less than 1 month of age, with eight in this group being between 28 and 32 weeks gestation (Table 1).

Absence of a patent ductus arteriosus was identified in 44 patients (Table 2). Seven cases in this group were shown in fact to have a patent ductus arteriosus, but in each case the ductus was assessed as being small by angiography or necropsy.

In the remaining 87 patients ductal patency was

Table 1 Age breakdown of total patient population

Age of patients	No. of cases
28 weeks gestation to term	8
Term to 1 month	75
1 to 6 months	21
6 months to 1 year	7
>1 year	20
	131

Table 2 Reliability of detection of patent ductus arteriosus

		State of ductus		
		Patent	Closed	
Echo prediction	Patent	87	0	87
	Closed	7	37	44
		94	37	131

diagnosed by identifying an open aortic and pulmonary end, with a free communication in between (Table 2). This was possible only when the lumen was within the

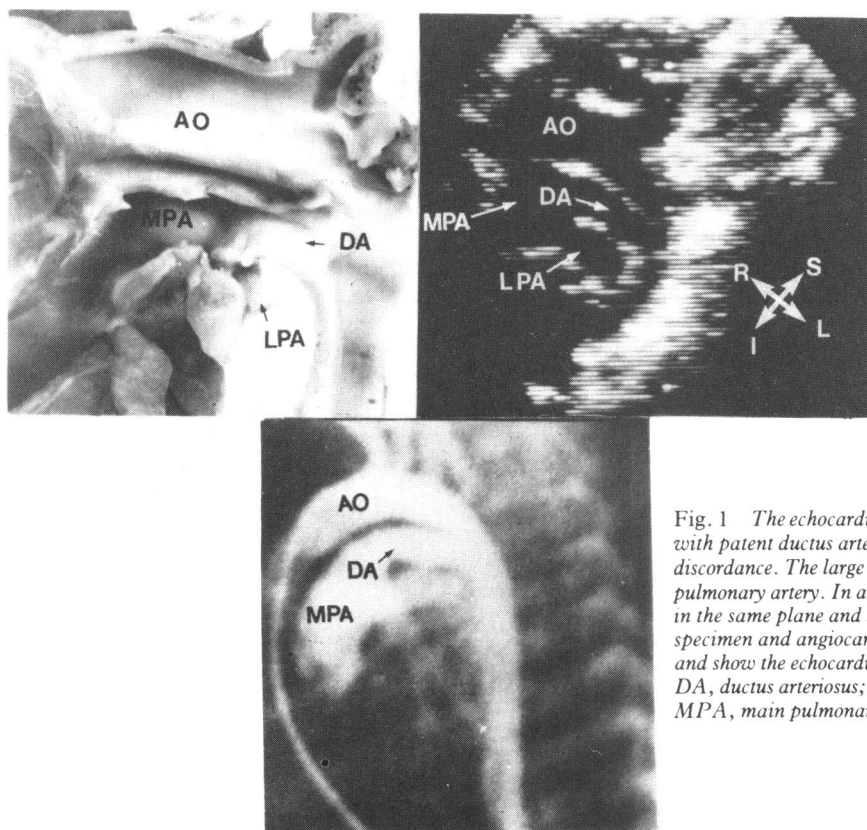


Fig. 1 The echocardiogram on the right is from a case with patent ductus arteriosus and ventriculoarterial discordance. The large ductus lies above the left pulmonary artery. In addition, the ductus and aorta are in the same plane and the ductal lumen is smooth. The specimen and angiogram are from the same case and show the echocardiographic features AO, aorta; DA, ductus arteriosus; LPA, left pulmonary artery; MPA, main pulmonary artery.

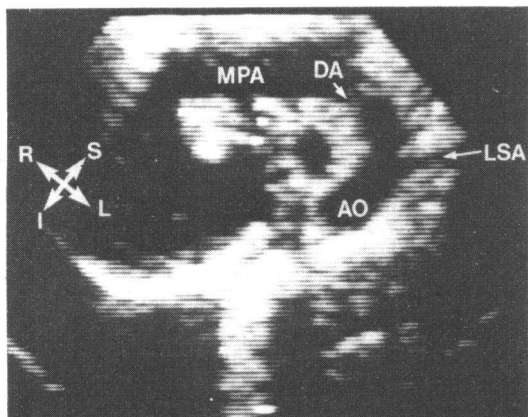


Fig. 2 The picture is from a case with interrupted aortic arch and patent ductus arteriosus. Note the origin of the left subclavian artery from the descending aorta. Also observe the irregular lumen of the ductus arteriosus. LSA, left subclavian artery. For the rest of the abbreviations see Fig. 1.

range of lateral resolution. It was also evident that in some cases the ductus had a smooth lining whereas in others the lumen was irregular (Fig. 1 and 2).

There were different morphological patterns depending on the ventriculoarterial connection and the presence of other aortic arch abnormalities. The results will therefore be presented according to the arterial connections.

VENTRICULOARTERIAL CONCORDANCE AND A NORMAL AORTIC ARCH (43 CASES)

In this group 25 had an isolated patent ductus arteriosus, and 18 had at least one associated cardiac defect. A

correct assessment of patency was possible in 38 cases. In the majority of cases the ductus was seen only when the transducer was angled towards the patient's left side, such that the main and left pulmonary arteries were clearly visualised. In this view the ductus lay above the left pulmonary artery and could be visualised along its entire length arising at an obtuse angle from the descending aorta (Fig. 3). In 15 patients it appeared wider at the aortic end than at the pulmonary end (Fig. 4). In those cases with persistent fetal circulation the main pulmonary artery, ductus, and descending aorta appeared as one continuous structure, with the aortic isthmus not being visualised in the same cut. By contrast, in those cases seen at a later stage, the descending aorta could be visualised on both sides of the ductus (Fig. 3).

In those cases with a large ductus, the aortic isthmus invariably was the narrowest point in the aorta. The first clue to the presence of a patent ductus in this group was often a ridge at the entry site of the ductus into the aorta (Fig. 5), that is on its anterior wall.

In the majority of cases it was not possible to visualise the aortic arch, main pulmonary artery, and ductus in the same cut. Exceptions, however, occurred in the low birthweight group and in some of the neonates with associated intracardiac defects (compare Fig. 3 and 4).

Three cases had pulmonary atresia and intact ventricular septum. In these patients the ductus arose from the descending aorta at a more obtuse angle than in cases with pulmonary atresia and ventricular septal defect, but more acutely than those cases with ventriculoarterial concordance and a normal pulmonary flow (Fig. 6). In those with pulmonary atresia and intact septum the isthmus was of equal calibre with the descending and ascending aorta.

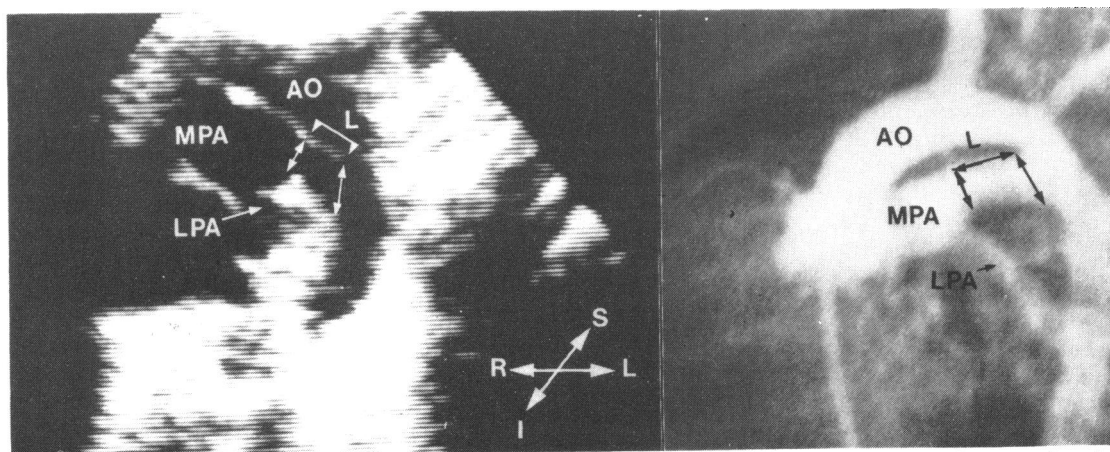


Fig. 3 The echocardiogram on the left is from a case with ventriculoarterial concordance and ductus arteriosus. The arrows show the aortic and pulmonary ends which are widely patent. The ductal length is indicated by the arrow lying between these two. The angiogram on the right is from the same patient showing the patent ductus. L, ductal length. For the rest of the abbreviations see Fig. 1.

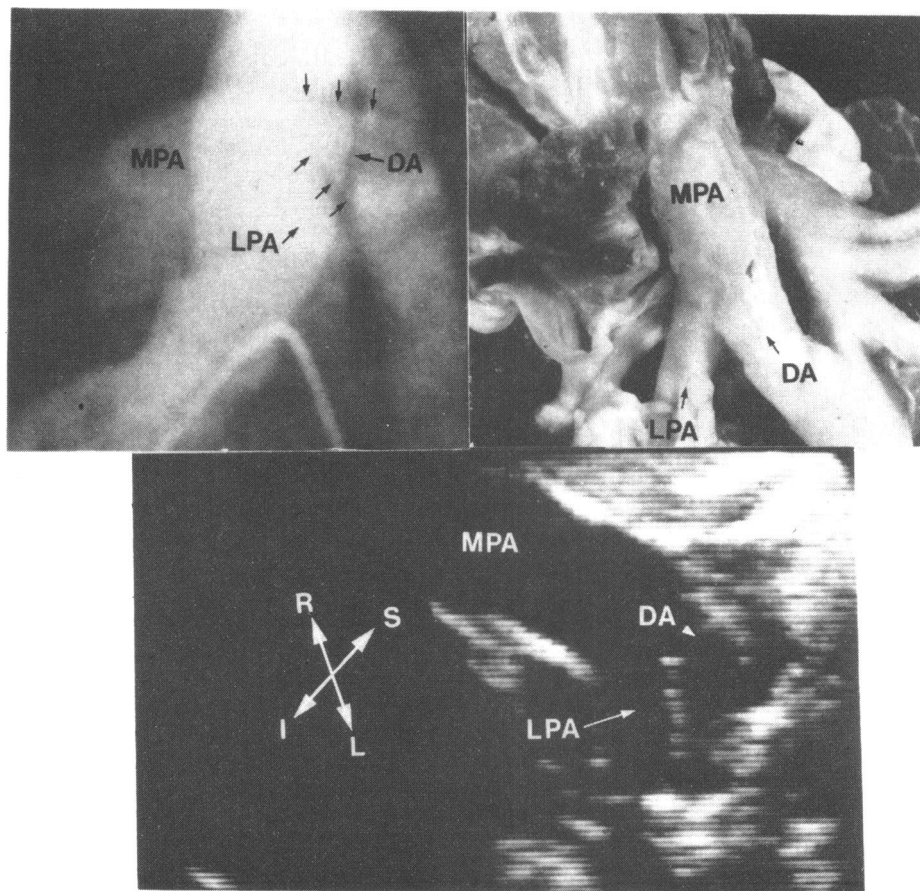


Fig. 4 The echocardiogram is from a case with ventriculoarterial concordance and patent ductus arteriosus where the ductus is narrower at the pulmonary artery than aortic end. The angiocardiogram is from the same case showing the above features. The specimen is from a different case showing the ductus arteriosus running above the left pulmonary artery. See Fig. 1 for abbreviations.

VENTRICULOARTERIAL DISCORDANCE (15 CASES)

In all but one case the ductus could be visualised at the same time as the aortic arch, main, and left pulmonary arteries (Fig. 1). Unlike those with ventriculoarterial concordance very little leftward angulation was necessary for visualisation. Again, the ductus appeared narrower at its pulmonary end than at its aortic end in seven cases. A correct assessment of patency was possible in all patients, with no false positive or false negative diagnosis of patency. In this group the aortic isthmus appeared to be of normal size, unlike in those cases with ventriculoarterial concordance and a significant ductus.

SINGLE OUTLET FROM HEART, AORTIC, AND PULMONARY ATRESIA (18 CASES)

In all cases patency was correctly identified. One patient had a truncus arteriosus and interrupted aortic

arch, the ductus being visualised distal to the origin of the pulmonary artery (Fig. 7). Thirteen cases had pulmonary atresia with ventricular septal defect. The aortic isthmus appeared normal in size in all cases and the ductus formed a more acute angle with the descending aorta than in patients with ventriculoarterial concordance or discordance (compare Fig. 1, 3, and 8). The transducer position necessary to visualise the ductus and patterns of origin obtained varied in those with pulmonary atresia and ventricular septal defect. Frequently the ductus appeared tortuous.

In the majority of cases the ductus could be seen arising from the underside of the aortic arch (Fig. 8). In one case, however, this appearance was absent. In this patient, who had a right aortic arch, the ductus arose from the left innominate artery. The orifice of the innominate artery appeared dilated and the large

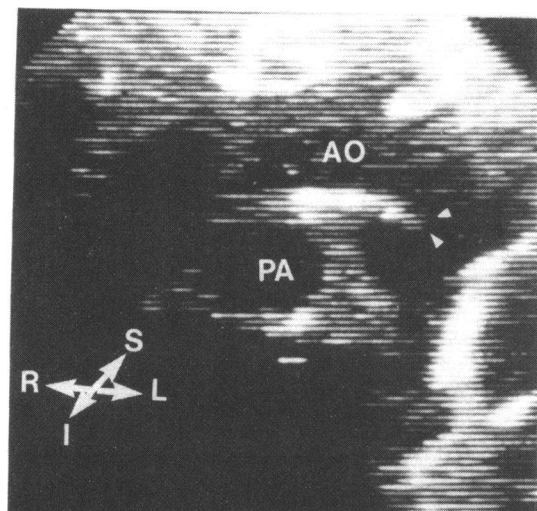


Fig. 5 The echocardiogram shows the aortic arch viewed from the suprasternal approach. The entry site of the duct is into the front wall of the aorta indicated by the arrows. The specimen is from a different case illustrating the entry site into the aorta. PA, pulmonary artery. For the rest of the abbreviations see Fig. 1.

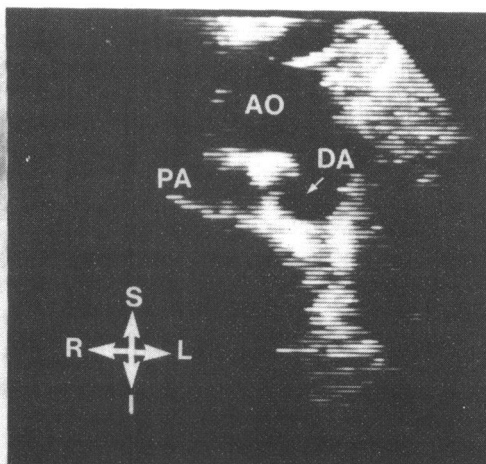
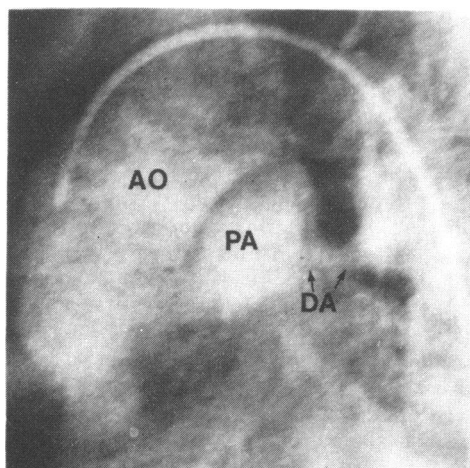
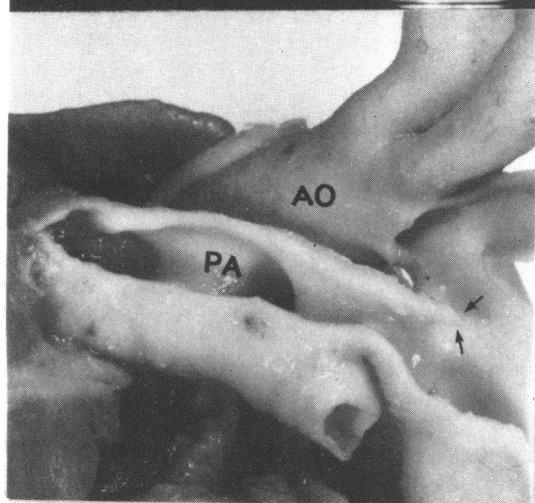


Fig. 6 The echocardiogram is from a case with pulmonary atresia and intact ventricular septum where the ductus is constricted in the middle. The ductus forms a more obtuse angle with the descending aorta than in Fig. 8 where pulmonary atresia and ventricular septal defect are present. The angiogram on the left is from the same case. For abbreviations see Fig. 1 and 5.

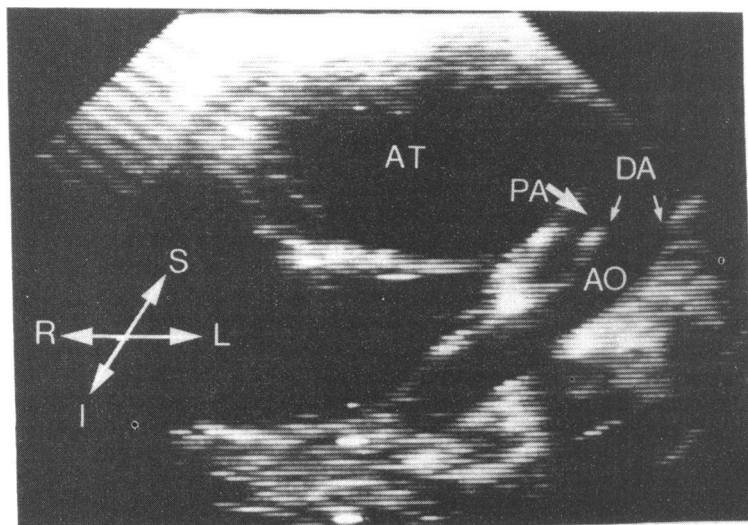


Fig. 7 This is from a case with truncus arteriosus, interrupted aortic arch, and patent ductus arteriosus. The large ascending trunk is seen which is continuous with the descending aorta via a ductus arteriosus. The origin of the pulmonary artery lies above the ductus. The walls of the ductus are smooth. AT, ascending trunk; AO, descending aorta. For the rest of the abbreviations see Fig. 1 and 5.

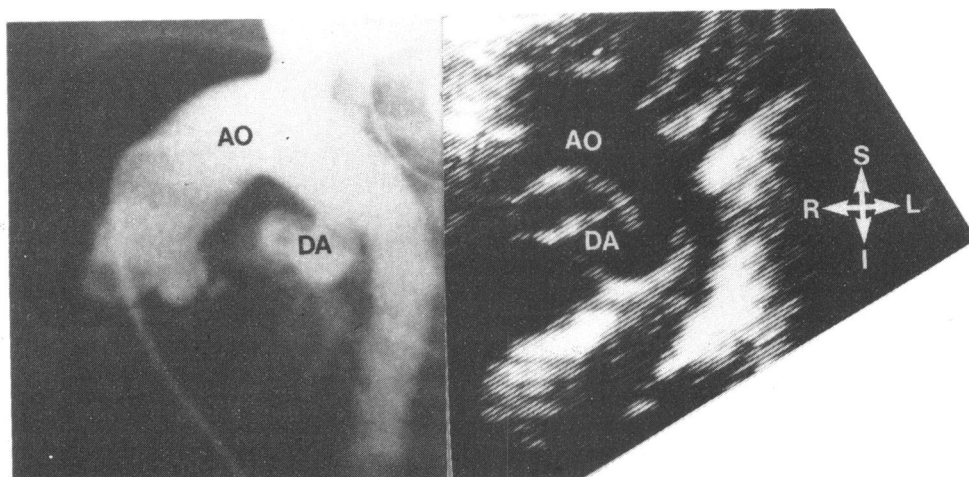


Fig. 8 The echocardiogram is from a case with pulmonary atresia and ventricular septal defect. The large ductus supplies the pulmonary arteries, and forms an acute angle with the descending aorta. The aortic isthmus is large. The angiogram on the left is from the same case. For abbreviations see Fig. 1.

ductus could be traced inferiorly to its point of communication with the pulmonary artery (Fig. 9).

In one other patient the left pulmonary artery was supplied by a left sided ductus originating from the underside of the aortic arch. The two pulmonary arteries were interrupted, with the right being supplied by a ductus originating at the base of the first brachiocephalic artery (Fig. 10).

Four cases had aortic atresia associated with mitral atresia and a hypoplastic left ventricle. The ductus appeared as a continuous structure between the main pulmonary artery and descending aorta (Fig. 11), with

the aorta above being visualised simultaneously in only one case. Again the ductal lumen appeared irregular in some and smooth in others.

COARCTATION OR INTERRUPTED AORTIC ARCH (18 CASES)

In all six cases with an interrupted aortic arch a correct assessment of patency was achieved. In three patients who presented in the first eight days of life in severe cardiac failure the lumen of the ductus appeared irregular (Fig. 2), unlike in those patients who presented at a later stage, in whom the lumen was smooth (Fig. 7). The

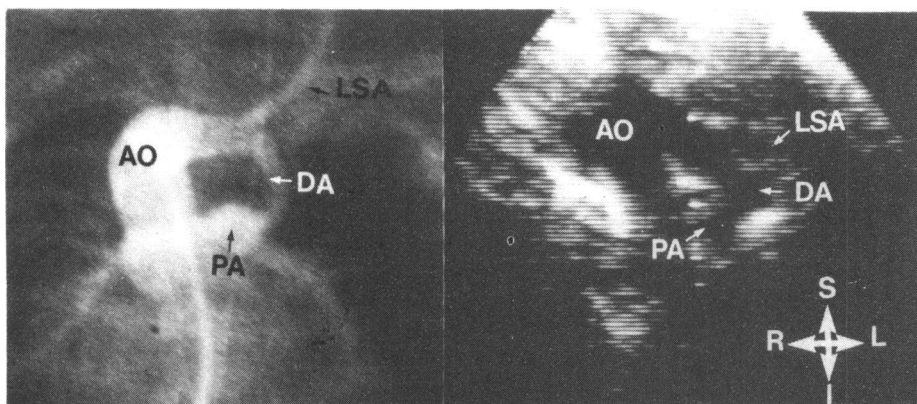


Fig. 9 The echocardiogram is from a case with pulmonary atresia, ventricular septal defect, and origin of the ductus from the left innominate artery. The angiogram on the left is from the same case. LSA, left subclavian artery. For the rest of the abbreviations see Fig. 1 and 5.

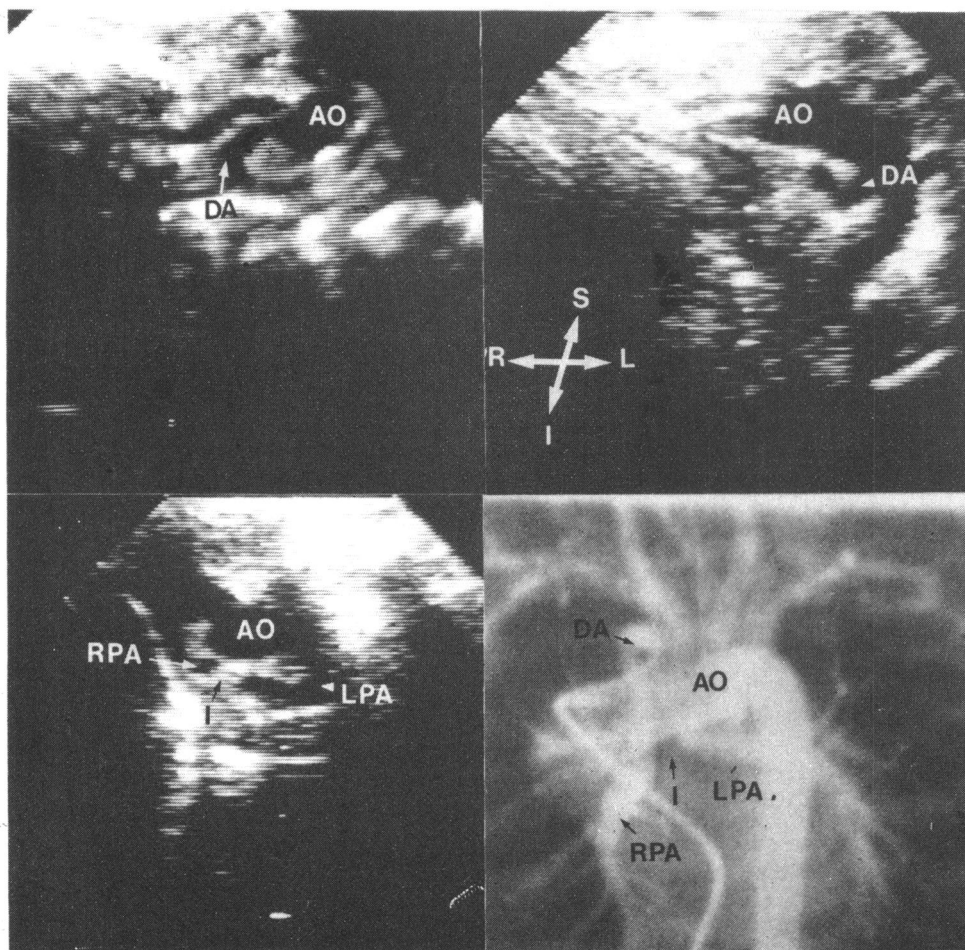


Fig. 10 The echocardiograms are from a case with pulmonary atresia, ventricular septal defect, bilateral ductuses, and interrupted pulmonary arteries. The upper right picture shows the origin of the left ductus. The upper left picture shows the origin of the right ductus supplying the right pulmonary artery. The lower left picture shows the left and right pulmonary arteries with the site of interruption. The angiogram is from the same case showing the bilateral ductuses and interrupted pulmonary arteries. I, interruption; RPA, right pulmonary artery. For the rest of the abbreviations see Fig. 1.

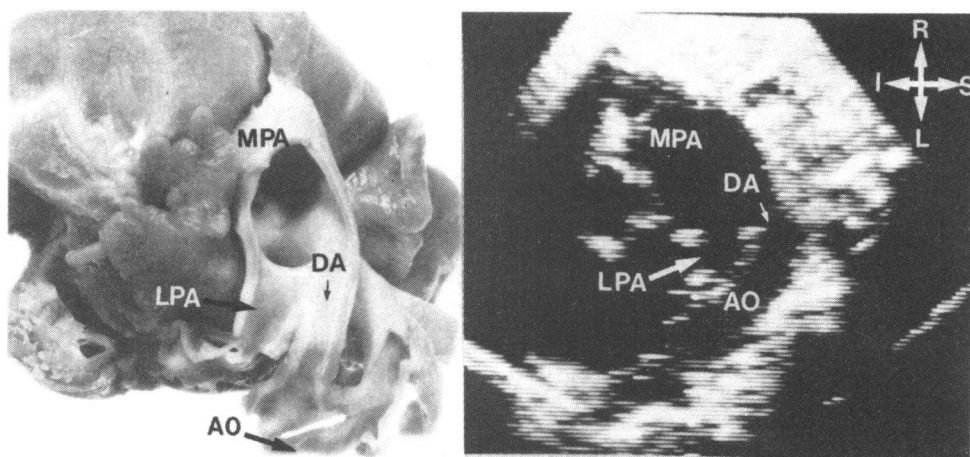


Fig. 11 The echocardiogram is from a case with hypoplastic left heart syndrome and patent ductus arteriosus. Note the inability to visualise the upper part of the descending aorta and duct in the same plane. The specimen on the left is from a different case with hypoplastic left heart and patent ductus arteriosus cut to simulate the echocardiographic features. For abbreviations see Fig. 1.

main pulmonary artery, ductus, and descending aorta appeared as one continuous structure with no aortic arch visualised proximal to the interruption. Each of these cases had interruption between the left carotid and subclavian arteries. In five cases it was possible to visualise the main, right, and left pulmonary arteries and ductus simultaneously, an appearance that was observed in only two other patients, one of whom had aortic atresia and the other coarctation of the aorta.

In 12 cases with coarctation of the aorta a correct assessment of patency was possible in 10. Direct visualisation of the ductus proved more difficult in this group, requiring longer periods of examination to outline the structure. Again the lumen of the ductus appeared irregular in some cases and smooth in others.

Discussion

Patent ductus arteriosus is one of the commonest lesions. When the typical clinical features are present, clinical diagnosis is easy, but many ductuses occur in association with intracardiac defects and these may mask the signs. In the premature baby similarly, the classical signs may be missing, despite the presence of isolated large patent ductus.

Cross-sectional echocardiography has made a major impact on the assessment of intracardiac anatomy but the detection of patent ductus arteriosus has remained elusive. Sahn and co-workers¹ used the precordial approach to image the ductus, but in our experience this view tends to foreshorten the vessel, and major problems arise in those conditions where the ductus does not occupy its usual position. Furthermore, in conditions with reduced pulmonary blood flow it is often very difficult reliably to visualise the pulmonary

artery and descending aorta from the precordium, because the small size of the pulmonary trunk permits lung to intrude between it and the transducer.

With increasing interest in newborn ductuses it has become increasingly important to develop a non-invasive technique which not only detects their presence, but also allows reliable estimation of size. The measurement of the left atrial to aortic ratio in the isolated ductus has played an important role, but is an indirect estimate and is not specific for patent ductus arteriosus.^{2,3}

Pulsed Doppler studies can indicate a left to right shunt at great vessel level but do not measure the size of the ductus.⁴ Both these techniques quantify left to right shunting, which, in the presence of a raised pulmonary vascular resistance, may not reflect the size of the ductus at all.

The first clue to the possible presence of a patent ductus arteriosus is obtained when the aorta is visualised in its long axis. In the majority of cases a protrusion from the medial wall into the lumen is seen. This represents the entry site of the ductus and can be used as a landmark when developing the ductus, with anti-clockwise and leftward movements of the transducer. It may also be seen when the ductus is closed, and does not indicate patency.

The most important aspect of the examination, independent of the arterial connections, is the identification of the left pulmonary artery. If this is not achieved during the study then patent ductus arteriosus will be overdiagnosed. The left lower lobe pulmonary artery is often seen alongside the descending aorta before it crosses it. Dropout may occur where the two structures cross, giving a false impression of a ductus arteriosus. It is not sufficient

only to visualise a vessel appearing to join the aorta. Both ductus and left pulmonary artery must be identified before one can be distinguished from the other. Similarly, in a cut where the main pulmonary artery and the transverse aorta cross, dropout frequently occurs where the vessels meet, giving the false impression of a ductus.

It appears that a large or moderate ductus can be reliably detected, but problems occur when the vessel is fairly small. This is because the demonstration of patency depends on visualisation of a continuous lumen from the aortic to the pulmonary artery end. Furthermore, when the vessel is less than 2 mm in size it will fall outside the range of lateral resolution of the equipment being used. This does not matter greatly, firstly because 1 to 2 mm ductuses are usually haemodynamically insignificant and secondly because these can probably be detected non-invasively with the combination of cross-sectional echocardiography and pulsed Doppler velocimetry. The other main problem is lack of direct visualisation because of a poor suprasternal window. The examiner must not concentrate on one position, but must be prepared to move the transducer to other sites in the neck or just below the clavicles. Care must be taken not to position the transducer too far below the clavicles. Accurate visualisation without foreshortening necessitates approaching the ductus from above so that its whole length can be seen. This is probably the single most important factor.

There still will be some patients, however, with respiratory problems where direct visualisation is impossible. Invariably in our experience this has been encountered in cases with a hypoplastic lung and mediastinal shift or upper airways obstruction (choanal atresia or stridor).

There is strongly suggestive evidence that a persistent ductus has a different macroscopical and histological appearance from one that will spontaneously close. The lumpy appearance of a closing ductus is a result of projecting intimal cushions which eventually meet in the middle before closure.⁵ This irregular appearance of the ductal lumen may be seen in some neonates who present early in life with a duct dependent circulation (Fig. 2). It differs from the smooth walled appearance of the ductus seen in some cases who present at a later stage with persistent ductus arteriosus (Fig. 7).

The appearance of a ductus in ventriculoarterial concordance is fairly constant in the majority of cases, with visualisation only being possible when the ascending aorta and arch are out of view. Simultaneous visualisation of the ductus and ascending aorta in the presence of ventriculoarterial concordance was only possible in some of the premature babies and one other patient with ductus arteriosus associated with Ebstein's malformation of the tricuspid valve. This is readily understood when one appreciates that in the majority

of cases the aorta and ductus are in a different plane.

By contrast, in ventriculoarterial discordance the very orientation of the great arteries enables easy visualisation, with the arch of the aorta and main pulmonary artery appearing simultaneously in almost all cases (compare Fig. 1 and 4).

When there is an associated interrupted aortic arch, the ductus, main pulmonary artery, and descending aorta appear as one continuous structure. When the left subclavian artery originates distal to the interruption, it can be seen arising from the descending aorta (Fig. 2).

It is well recognised from angiocardigraphic and morphological studies that the ductus in pulmonary atresia may vary in appearance.⁶ In cases with pulmonary atresia and intact ventricular septum, with a good sized right ventricular cavity, the ductus appears to follow the normal pattern, with an obtuse angle between itself and the descending aorta. In contrast, in patients with a small right ventricular cavity or pulmonary atresia and ventricular septal defect the duct may be irregular and forms an acute angle with the descending aorta. These differing appearances are probably related to varying patterns of flow through the ductus in utero, and are readily identified by cross-sectional echocardiography. In our experience it is only from the suprasternal region that the ductus in those cases with a low pulmonary flow can be visualised. The examiner must also be aware of atypical origin of the ductus, usually in cases of pulmonary atresia and ventricular septal defect, as for example in cases where the left sided ductus arises from the innominate artery in patients with a right aortic arch. A clue to the presence of a ductus arising from one of the brachiocephalic vessels should be the inability to identify a ductus arising from the underside of the aorta. Likewise, bilateral ducts, usually associated with interruption of the pulmonary arteries, must always be excluded.

It is well recognised that the ductus usually closes at its pulmonary artery end, leaving in many cases a ductus diverticulum on the aorta. Occasionally the aortic end may close first, resulting in a dimple appearing at the pulmonary artery end (Fig. 12). In other cases the ductus may close in the middle leaving a dimple on the aortic and pulmonary artery ends (Fig. 6). For these reasons it is vital that the examiner visualises the ductus along its total length, or an incorrect assessment of patency will be made. These appearances are well shown by cross-sectional echocardiography.

Direct non-invasive imaging of the ductus provides for the first time a method of monitoring the effects of pharmacological manipulation of the ductus. By repeated cross-sectional examination it is possible, for example, to watch closure of the ductus after administering indomethacin or withdrawing prostaglandin.

Thus with cross-sectional echocardiography the varying morphological patterns of a patent ductus

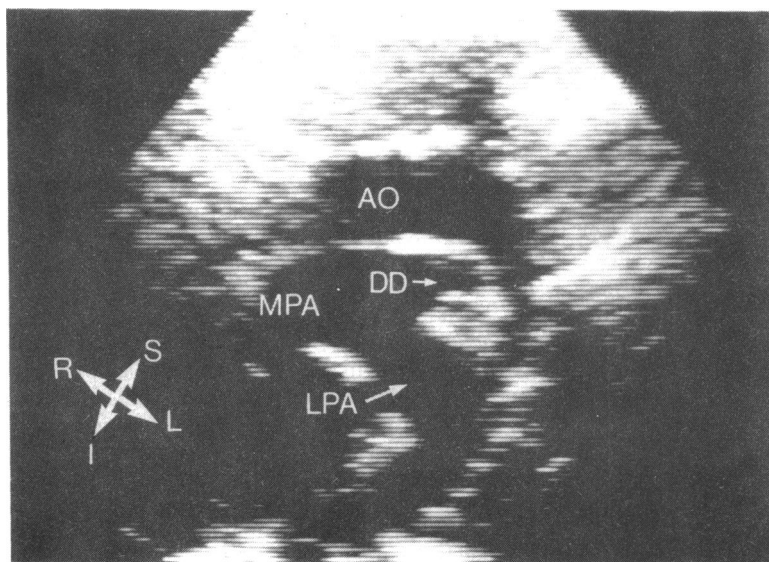


Fig. 12 The picture is from a case with ventriculoarterial discordance and a ductal constriction at the aortic end. Note the ductus dimple and the closed aortic end of the duct. DD, ductus dimple. For the rest of the abbreviations see Fig. 1.

arteriosus can be reliably visualised, provided the lumen falls within the range of lateral resolution of the equipment being used.

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